Effects of Closing Blocks on Hazard Areas

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ABSTRACT

A series of tests were conducted with reduced scale magazines to study the blast reduction effectiveness of closing blocks placed at the entrances of storage chambers of underground ammunition storage magazines.

Five small-scale magazines were made of reinforced concrete to investigate design features affecting the effectiveness of closing blocks. Three intermediate-scale magazines were constructed in hard rock to know the effectiveness of the blocks in magazines larger than the small-scale ones in real rock.

Pressure-time histories measured in the free field were analyzed, and the blast-hazard area of each magazine was calculated according to the procedures of DoD explosive safety regulation.

In our small-scale tests, the relative hazard area was strongly dependent on the chamber loading density and the areal density of the closing blocks, showing that the relative hazard area decreases with increasing chamber loading density and with decreasing areal density. We made some assumptions on the motion of closing blocks of our small-scale tests. It was shown that the relative hazard area was reduced by the increase in the initial acceleration, which was inversely proportional to the closing time. We obtained the equation representing the relative hazard area as a function of initial acceleration.

All three of the intermediate-scale magazines worked effectively: The hazard area for each magazine was reduced to about 10% of that calculated according to the procedures of the DoD safety regulation.

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1. INTRODUCTION

The ROK and the US are jointly developing new designs of underground ammunition storage facilities that will significantly reduce the hazard areas surrounding ammunition storage sites. One of the potential design concepts is a multi-chamber facility equipped with hazard control features. Among the hazard control features that is being investigated are constrictions, chamber/tunnel closing devices, expansion chambers, external barricade, and so on.

The closing block is a kind of chamber/tunnel closing devices which is placed at the entrance of storage chamber. A certain type of closing block, sometimes called KIotz Plug, was tested in full scale and small scale in Sweden and Norway (2) respectively in 1970's and proved to be effective in reducing blast hazard areas around underground ammunition storages. We want to find another design of closing block which is suitable for our own situation, especially easy in construction.

We tested closing blocks of trapezoidal prism shape in small-scale and intermediate-scale. Small-scale tests were conducted to investigate factors affecting the effectiveness of closing blocks.

Intermediate-scale tests were conducted to investigate the effectiveness of the closing blocks of trapezoidal prism type in magazines larger than the small-scale ones in real rock and to compare them with the closing block of KIotz Plug type.

Four designs of trapezoidal prism type were tested in small scale. We change the loading densities of storage chambers and areal densities of the blocks facing the explosive charges for tests in the small-scale model magazines. Pressure-time histories measured in the free field were analyzed to obtain the blast-hazard area of each magazine and compared with the one calculated according to the procedures of the DoD explosive safety regulations [3].

The blast hazard area became smaller for larger loading density of the storage chamber, smaller areal density of the closing block and larger initial acceleration.

Two designs of trapezoidal prism type and a design of KIotz Plug type were tested in intermediate scale. All of them worked quite effectively and each magazine showed the blast hazard area of about 10% of the one calculated according to the procedures of the DoD safety regulations.

2. THE TEST MAGAZINES

Five small-scale magazines were made of reinforced concrete to investigate factors affecting the effectiveness of closing blocks, as shown in Figs. 1-4. The four different small-scale magazines were denoted by S_1, S_2, S_3, and S_4 depending on the dimension of storage chamber and the closing block. In Figs. 1-4, "I" denotes a storage chamber, "II" a closing block, "III" and "IV" a chamber access tunnel, "V" and "VI" a main access tunnel, and "VII" an opening through which an explosive charge can be put into the chamber. The storage chambers were lined with 3.0 mm-thick steel plate and had reinforced concrete wall of 1.0 m thickness. The dimensions of inside spaces of storage chambers are shown in the right-bottom coners of Figs. 1-4, where the spaces for closing blocks are excluded.

Ready mixed concrete was poured into a steel box of trapezoidal prism shape to make a closing block. The steel box was made of steel plate of 3.0 mm thickness. Four closing blocks with different dimensions were designed to vary the areal density, mass divided by area, of the block surface facing the explosive charges. Details of the closing blocks are shown in the left-bottom corner of Figs. 1-4. To minimize friction between the floor and the closing block, three 10 mm diameter steel rods were welded under the bottom of the closing blocks. A closing block was placed at the entrance of storage chamber so that a space of 10 cm width and 23 cm height was formed for access to the storage chamber, which is denoted by access tunnel III in the Figs. 1-4. The access tunnel IV and V were steel tubes placed in reinforced concrete and their crossections were squre of 10 cm x 10 cm and 20 cm x 20 cm respectively. Access tunnel VI were steel pipe of 19.6 cm inner diameter and 1.0 cm thickness. Every small-scale magazine has two open ends of access tunnel. A hole of 20 cm diameter was made through a wall of storage magazine to place an explosive charge in the chamber for testing, which was denoted by VII in Figs. 1-4. The hole was plugged by using a concrete bar after placing the explosive. The concrete part of a magazine including the storage chamber was covered with soil of 3.0 m thickness in minimum.

Two intermediate-scale magazines were constructed in rock to investigate the effectiveness of closing blocks of trapezoidal prism type in magazines larger than the small-scale ones in real rock. Closing block and storage chamber of magazine I_1 resembled those of Magazine S_3 as shown in the first drawing of Fig. 5. In the design of Magazine I_2 shown in the third drawing of Fig.S, the chamber access tunnel around a closing block of trapezoidal prism type was modified to prevent the high pressure gas, trapped in the chamber access tunnel III, retarding the motion of the block. Fig. 5 also shows another intermediate-scale magazine, Magazine I_3, which had a closing block of KIotz Plug type and was constructed to compare its effectiveness with those of trapezodial prism type. Every intermediate-scale magazine has one open end of access tunnel.

Table 1 shows volumes of storage chamber(V_C), volumes of magazine magazines(V_t), masses of closing blocks(M), and areas of closing blocks facing the explosive charges(A), which were measured after construction.

Table 1. Properties of Magazines

Magazine	$V_c(m^3)$	$V_t(m^3)$	M(kg)	$A(m^2)$
S_1	0.115	0.447	53	0.084
S_2	0.115	0.478	112	0.176
S_3	0.115	0.456	28	0.084
S_4	0.115	0.458	35	0.084
I_1	9.208	98.732	1764	1.302

Table 1. Properties of Magazines

3. EXPERIMENTAL

The explosive detonated for each of the small-scale tests was 2.3 kg or 4.6 kg Comp C4, which gives a chamber loading density of 20 kg/m^3 or 40 kg/m^3, respectively, as shown in Table 2. The explosive detonated for each of the intermediate-scale tests was 243 kg Comp C4, which gives a chamber loading density of 18.8 26.4 kg/m^3 and a total loading density of 1.7 ~ 2.5 kg/m^3 as also shown in Table 2.

Table 2. Explosive Loading Densities

Magazine	Chamber Loading Density (kg/m^3)	Total Loading Density (kg/m^3)
S_1 (40 kg/m^3)	40.0	10.3
S_1 (20 kg/m^3)	20.0	5.2
S_2	40.0	9.6
S_3	40.0	10.1
S_4	40.0	10.0
I_1	26.4	2.5
I_2	18.8	1.9
I_3	23.4	1.7

Table 2. Explosive Loading Densities

Pressure-time histories of blastwave in the free-field were recorded at locations shown in Fig. 6 by using piezo-electric gauges. A PCB gauge was mounted flush with the level ground by using gauge mount to measure the static pressure, and a normal surface was placed on the same gauge mount as the former to measure the stagnation pressure. Most of the gauges were placed to measure static pressures, and the stagnation pressures were measured only for reference. Gauge mounts for static pressure and stagnation pressure are shown in Fig. 7.

The instrumentation system consisted of pressure gauges, signal conditioning amplifiers (PCB 464A), a waveform digitizing system (Nic 500) and a personal computer as shown in Fig. 8.

Typical (static) pressure- time and impulse- time histories are shown in Fig. 9, which were measured in the free field at distance of 12m, 24m and 48m, respectively, along the 0° direction of the Magazine $_{I}$ test.

4. RESULTS AND DISCUSSIONS

The scaled static pressures, Pw/P, measured in the free field along the 0° lines are shown with respect to the scaled distances, R/Dt, in Fig. 10 for small-scale tests. P, R, P_w and D_t are peak pressure, distance from the opening, effective overpressure at the opening, and effective hydraulic diameter of the tunnel respectively. It can be seen, by comparing the scaled blast pressure of the 40 kg/m^3 tests each other, that Magazine S_3 showed the best sealing effect among the small-scale magazines, and that closing block was not very effective in the 20 kg/m^3 test.

The experimental data for each small-scale test and each direction were fitted to the equation,

$$Pw/P = a(R/D_t)^{1.35} \quad \cdots\cdots\cdots \quad (1)$$

The fitted results are summarized in Table 3, where the cofficient a's are shown for each direction of 0°, 30°, 60° and 90° of each test.

Table 3. Coefficient "a" and relative hazard area for each small-scale magazine

Magizine	0°	30°	60°	90°	RHAR
S_1(40 Kg/m^3)	2.52	3.07	3.77	6.52	0.31
S_1(20 kg/m^3)	1.38	1.86	2.91	4.95	0.61
S_2(40 kg/m^3)	2.74	3.32	4.11	7.32	0.28
S_3(40 kg/m^3)	3.37	4.91	6.88	10.52	0.16
S_4(40 kg/m^3)	2.74	3.46	4.49	7.26	0.26

Table 3. Coefficient "a" and relative hazard area for each small-scale magazine

The relative hazard area(RHAR) is the ratio of the hazard area of this test to that of the DOD safety regulations. The hazard distance of this test was obtained by using Eq.(1), where coefficient "a" was the value shown in Table 3 and pressure P is 1.2 psi. The hazard distance of the DoD safety regulation was obtained with the same process as above, except that coefficient "a" was taken to be

EQUATION

$$a = [\ 1 + (\theta/56)^2\ ] \quad \cdots\cdots\cdots \quad (2)$$

Listed in table 4 are chamber loading density, areal density and relative hazard area for each small-scale magazine, where areal density is mass of a closing block divided by the area of the block surface facing the explosive.

Table 4. Analysis of small-scale tests

Magazine	Chamber Loading Density (kg/m^3)	Areal Density (kg/m^2)	Initial Acceleration (m/s^2)	Relative Hazard Area
S_1	40	631	14640	0.31
S_1	20	631	10720	0.61
S_2	40	636	14520	0.28
S_3	40	333	27720	0.16
S_4	40	417	22140	0.26

Table 4. Analysis of small-scale tests

It can be seen that relative hazard areas are closely dependent on the areal density and loading density: The relative hazard area decreases as the loading density increases or the areal density decreases.

The effectiveness of a closing block will be determined by the closing time relative to the duration of blastwave as far as it is not broken into pieces. It would be reasonable to assume that the block would obtain most of its final velocity at the initial stage of its travel before the blastwave surrounds the block completely and moves with nearly constant speed afterwards. At the initial stage the blastwave from the explosive will accelerate the block by giving initial acceleration of

$$a_i = F/m = PA/m \quad \cdots\cdots\cdots \quad (3)$$

where P, A and m are pressure of blastwave acting on and area of the block surface facing the explosive, and mass of the block respectively. If we further assume that the initial acceleration continues until the blastwave surrounds the block completely, closing time will be given by

$$t_c = d / a_i t_i \quad \cdots\cdots\cdots \quad (4)$$

where d and ti are distance to move and time for surrounding the block completely respectively. Since the magazines of our small-scale tests have nearly the same d/ti values, the closing times are inversely proportional to the initial accelerations, approximately, and we plotted the relative hazard area as a function of initial acceleration as shown in Fig.Il by taking the pressure P as I

$$P = 17.7(Q/Vc)^{0.45} \quad \cdots\cdots\cdots \quad (5)$$

where Q and Vc are weight of explosive and volume of the storage chamber respectively. The plots of Fig.1l can be represented by

$$RHAR = \exp(-0.00007\ a_i) \quad \cdots\cdots \quad (6)$$

and the exact numbers of the plots is shown in Table 4. We can see from the above that the relative hazard area decreases as the initial acceleration increases and, thus, as the closing time decreases.

The scaled blast pressures, Pw/P, measured in the free field along the 0° lines are shown with respect to the scaled distances, R/Dt, in Fig. 12 for intermediate-scale tests. The experimental data for each intermediate-scale test and each direction were fitted to Eq. (1) and summarized in Table 5. Listed in Table 6 are chamber loading density, areal density and relative hazard area for each intermediate-scale magazine.

It can be seen that all three of the intermediate-scale magazines worked quite effectively and each magazine showed the blast hazard area of about 10% of the one calculated according to the procedures of the DoD safety regulation.

Although the blocks of Magazine I2 and I had much smaller initial acceleration than that of Magazine Ii, Magazine I2 and I showed almost the same relative hazard areas as that of the Magazine Ii, because the retarding force on the back side of the blocks of Magazine I_2 and $_I$ would be smaller than that of Magazine Ii due to the geometry around the blocks: The guiding concrete pillar delayed the blastwave reaching the back side of the block in Magazine $_I$, and the geometry of the access tunnel of Magazine I2 prevented the blastwave being trapped at the back side of the block.

Table 5. Coefficient "a" and relative harzard area for each intermediate-scale magazine

Magazine	0°	30°	60°	90°	RHAR
I_1	5.10	6.07	6.37	12.65	0.090
I_2	4.60	---	---	---	0.104
I_3	4.30	---	---	---	0.117

Table 5.
Coefficient "a" and relative harzard area for each intermediate- scale magazine

Table 6. Analysis of intermediate-scale tests

Magazine	Chamber Loading Density (kg/m^3)	Areal Density (kg/m^2)	Initial Acceleration (m/s^2)	Relative Hazard Area
I_1	26.4	1365	5699	0.090
I_2	19.8	2044	3293	0.104
I_3	23.4	3065	2401	0.117

Table 6. Analysis of intermediate-scale tests

5. CONCLUSIONS

A series of tests were conducted with reduced scale magazines to study the blast reduction effectiveness of closing blocks placed at the entrances of storage chambers of underground ammunication storage magazines.

In our small-scale tests, the relative hazard area was strongly dependent on the chamber loading density and the areal density of the closing blocks, showing that the relative hazard area decreases with increasing chamber loading density and with decreasing areal density. We made some assumptions on the motion of closing blocks of our small-scale tests. It was shown that the relative hazard area was reduced by the increase in the initial acceleration, which was inversely proportional to the closing time. We obtained the equation representing the relative hazard area as a function of initial acceleration.

All three of the intermediate-scale magazines worked effectively: The hazard area for each magazine was reduced to about 10% of that calculated according to the procedures of the DoD safety regulation. It seems that the increase of relative hazard area due to small initial acceleration was compensated by the effect of decrease in retarding force on the block due to the geometry of the magazine around the closing block.

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(2) E. Abrahamsson, "Operating block" Report No. 119:5 Reg. No. 4753F, Royal Swedish Fortifications Administration, Stockholm, May 1974.

(3) "DoD ammunition and explosives safety standards" DoD 6055.9-STD, Asst. Secretary of Defence, Washington, D.C., October 1992.

Fig. 1. Small-scale magazine : Magazine S_1

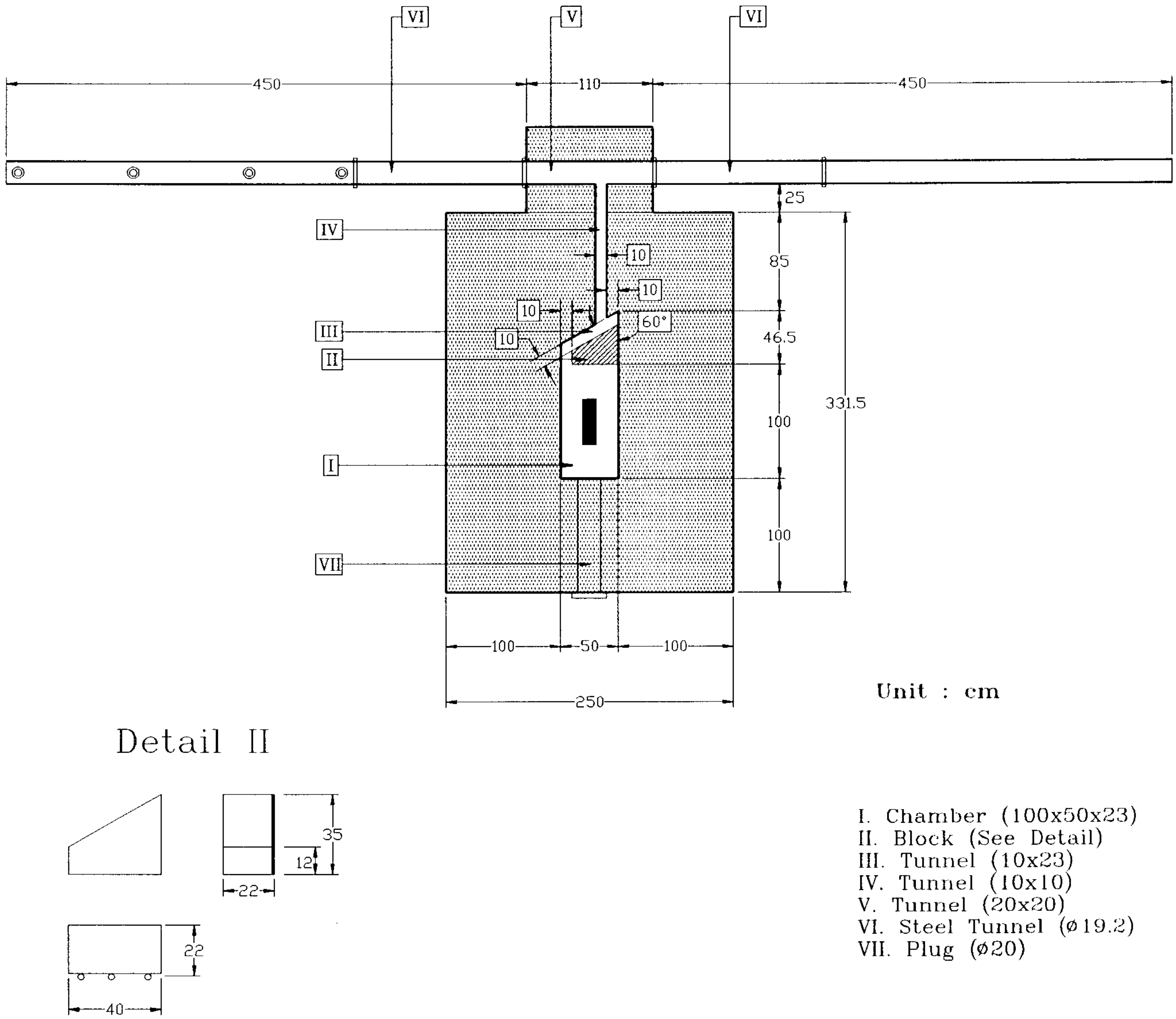


Fig.1. Small-scale magazine : Magazine S_1

Fig.2. Small-scale magazine : Magazine S_2

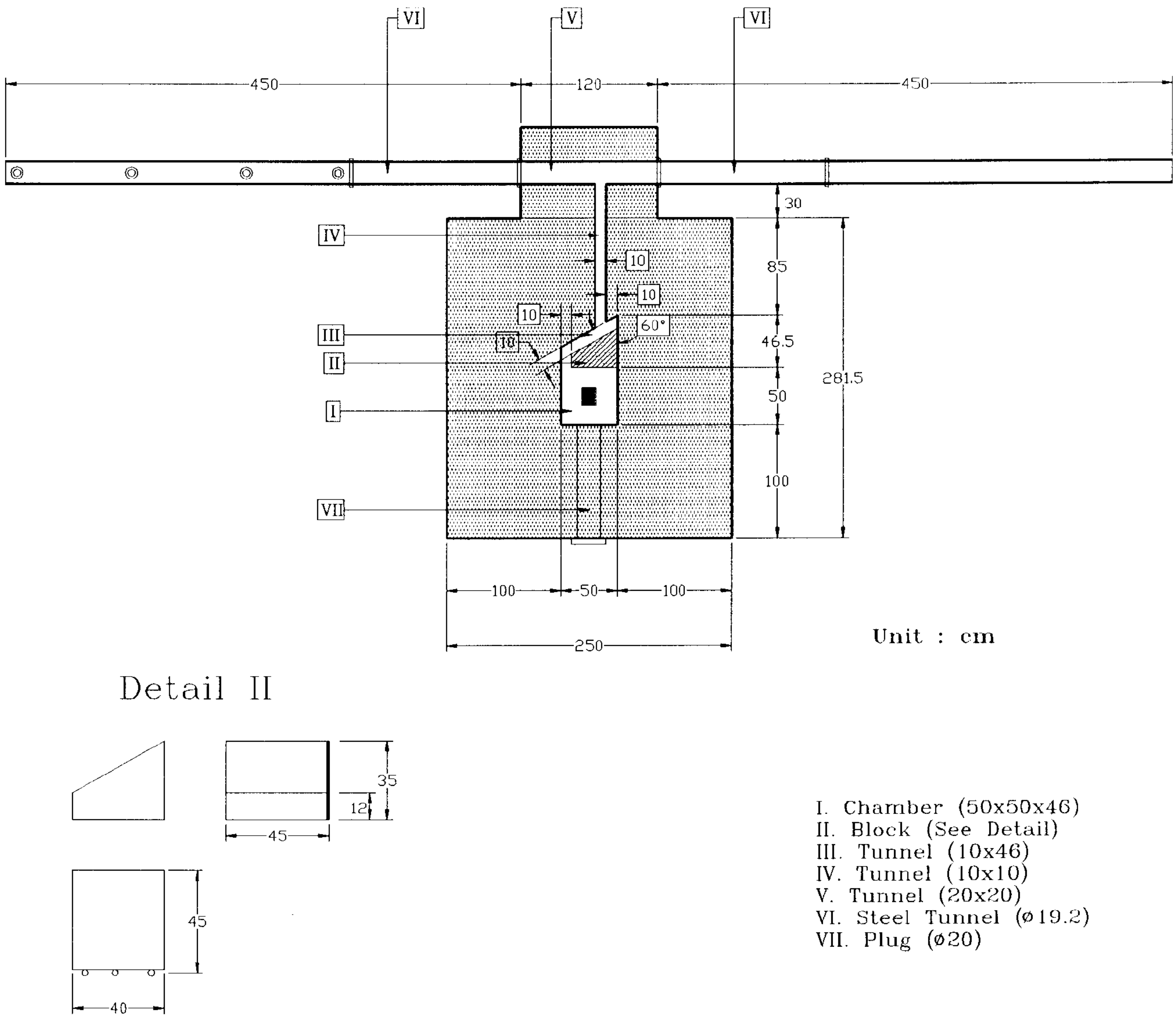


Fig.2. Small-scale magazine : Magazine S_2

Fig.3. Small-scale magazine : Magazine S_3

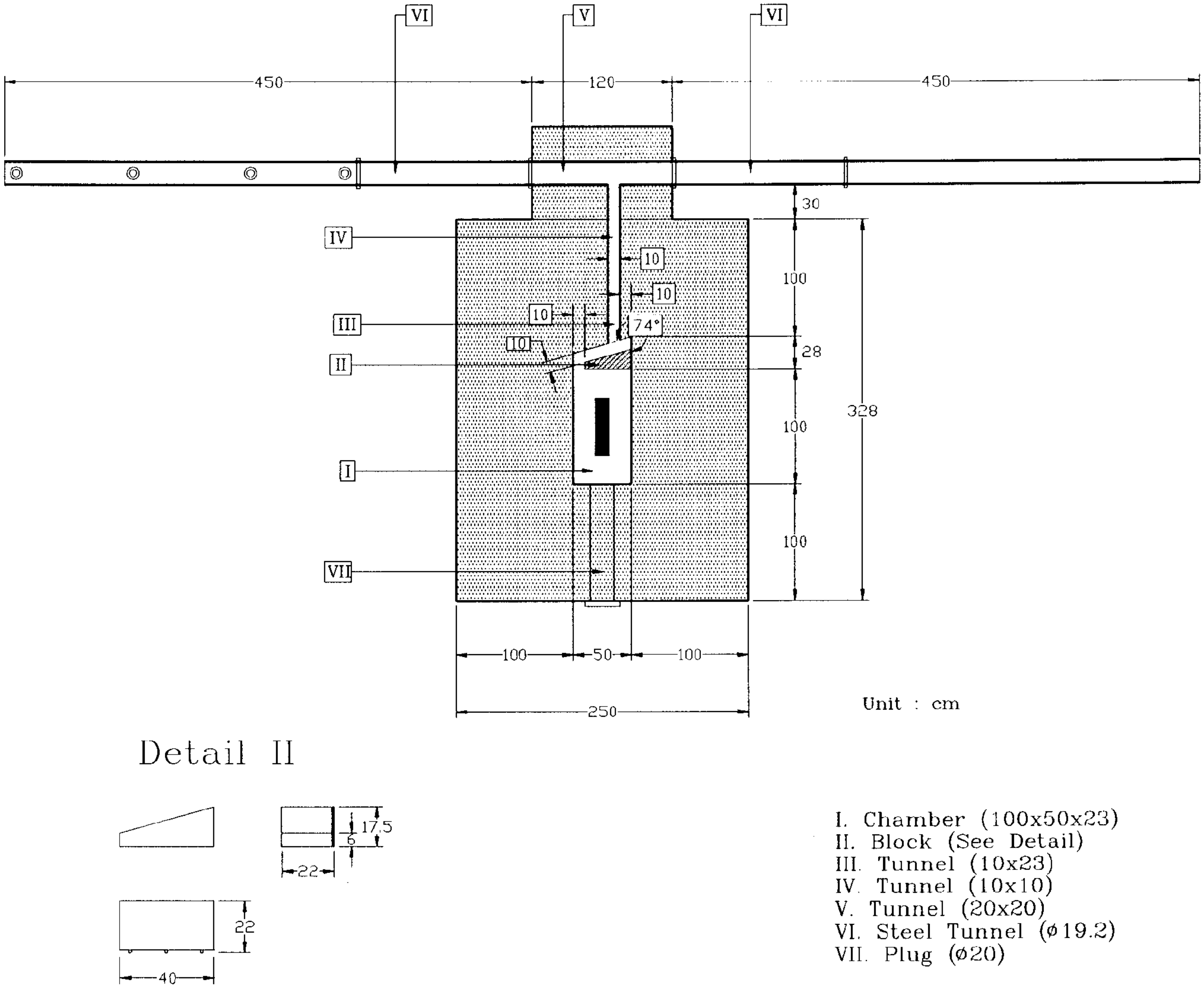


Fig.3. Small-scale magazine : Magazine S_3

Fig.4. Small-scale magazine : Magazine S_4

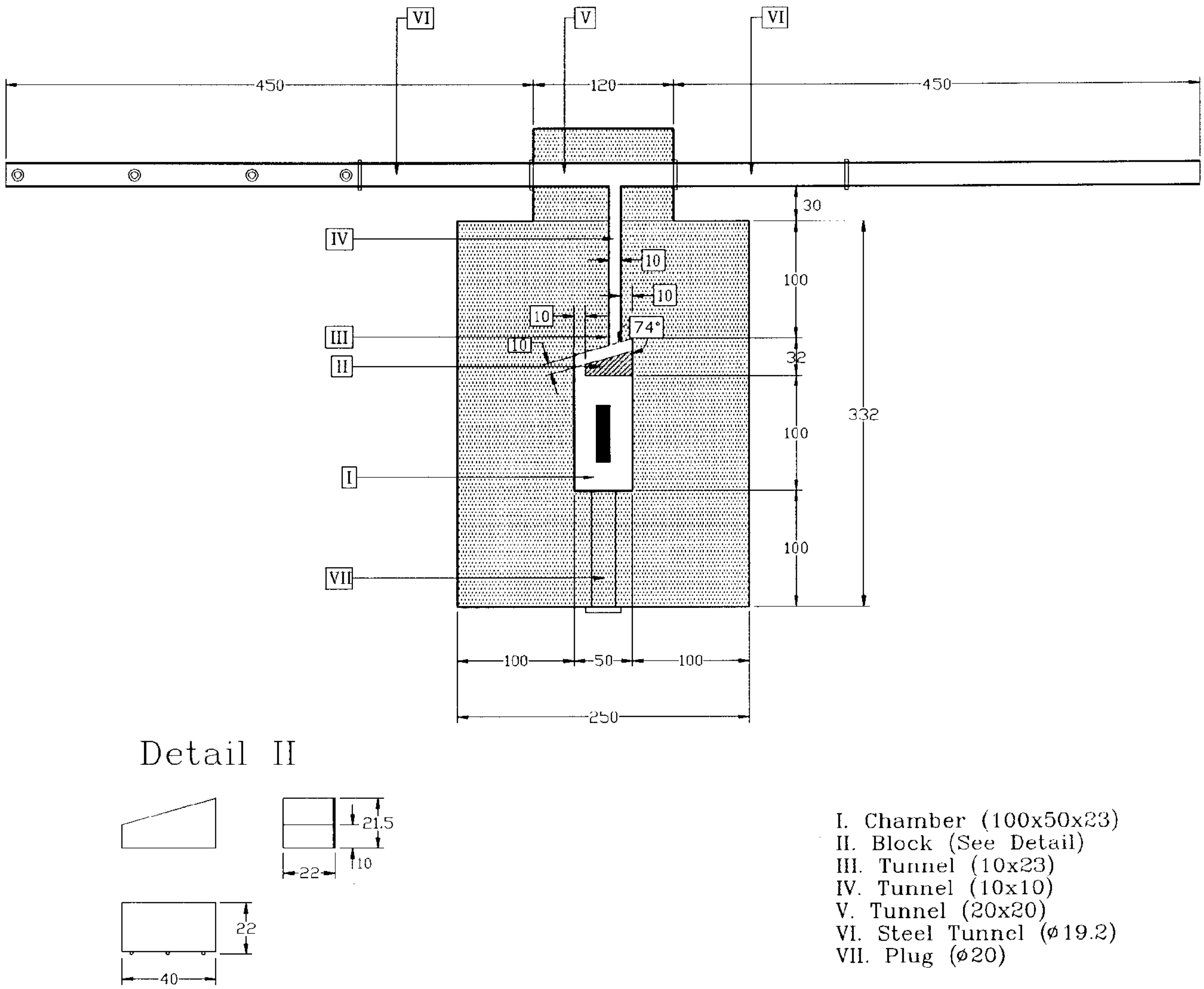


Fig.4. Small–scale magazine : Magazine S_4

Fig. 5. Intermediate-scale magazine.

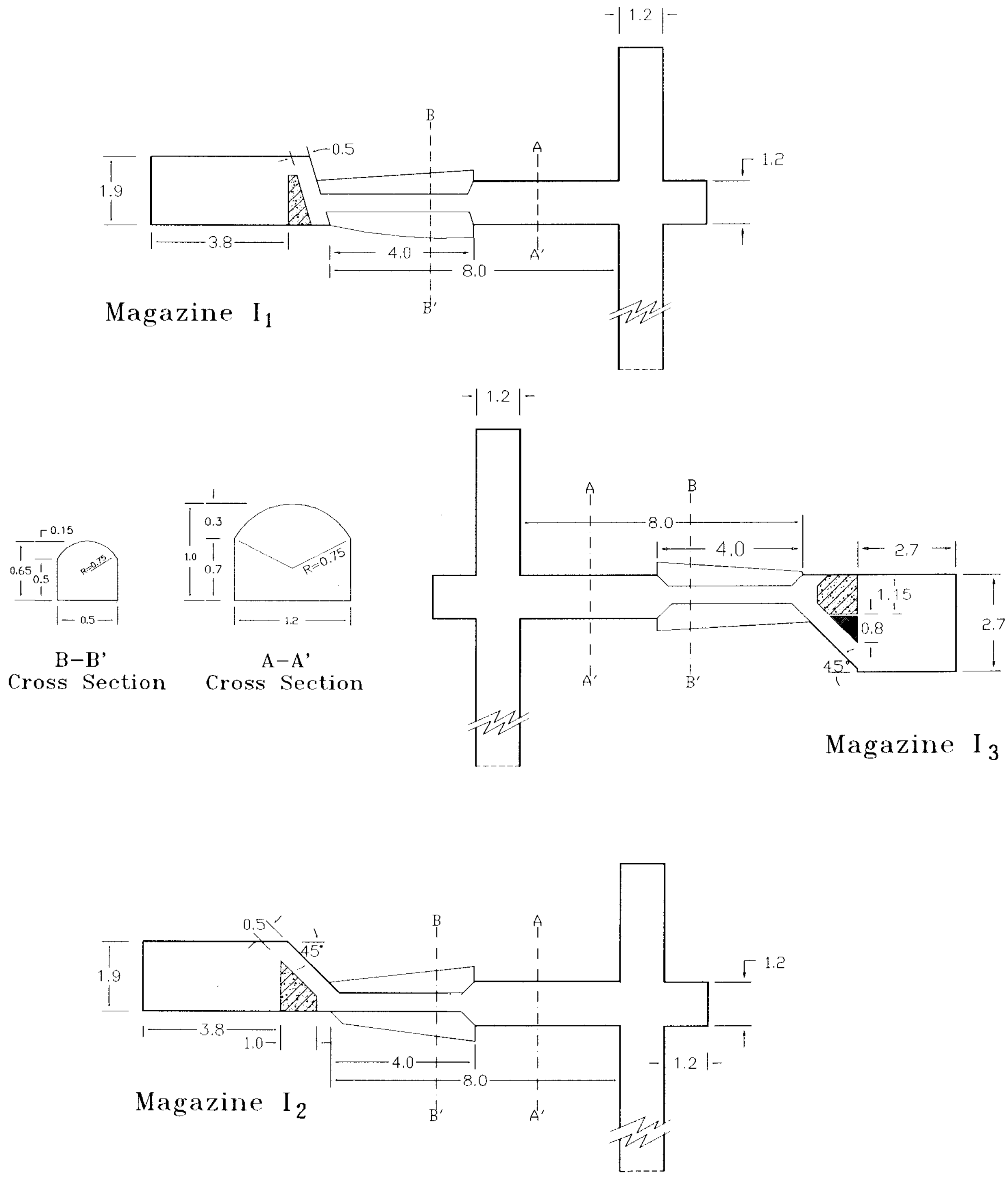
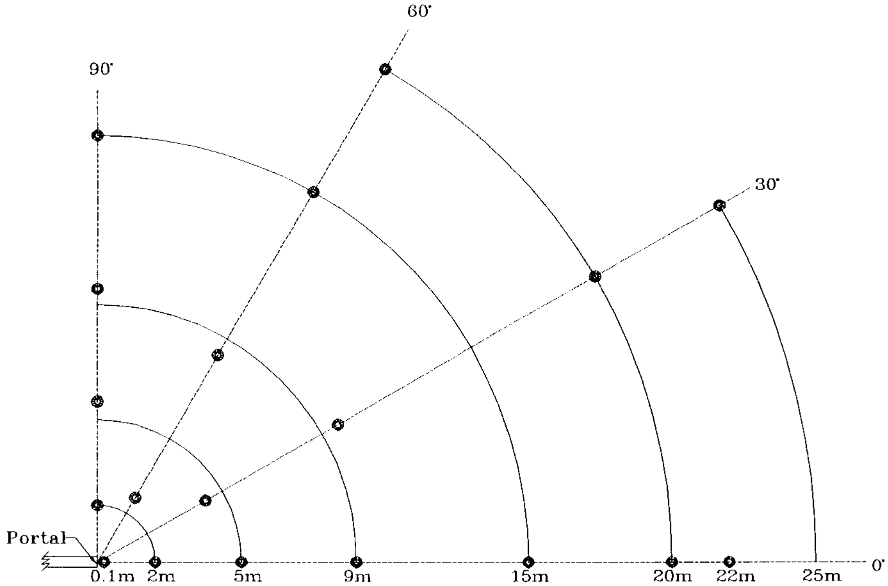


Fig. 5. Intermediate-scale magazine.

Fig. 6. Locations of pressure gauges in the free field.



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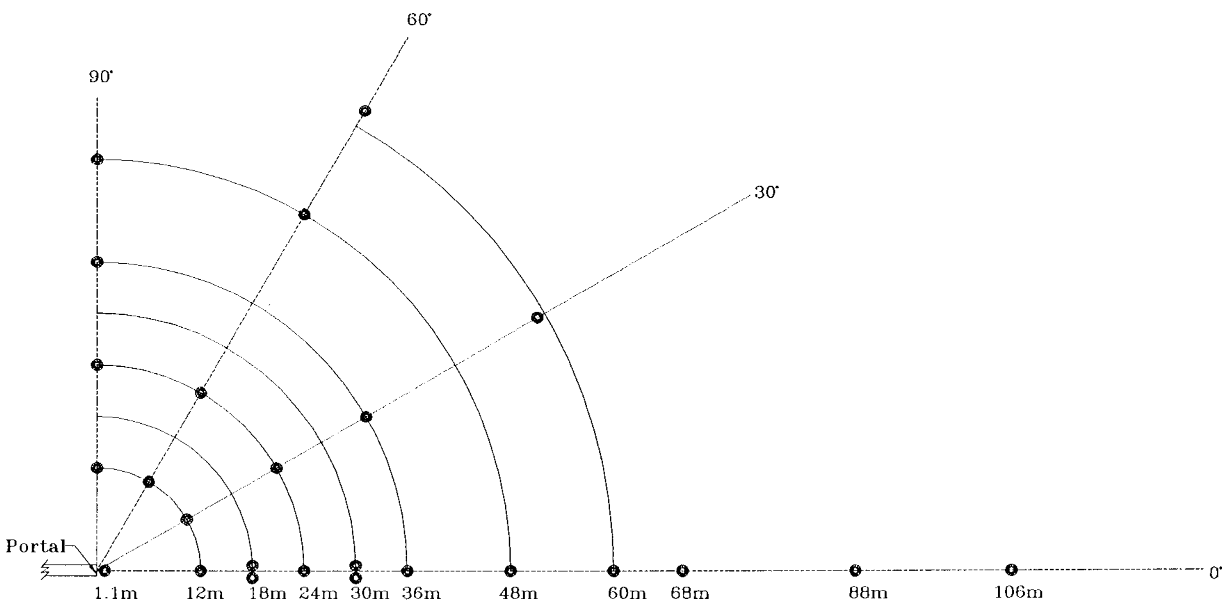

<Intermediate-scale tests>

Fig. 6. Locations of pressure gauges in the free field.

Fig. 7. Gauge mounts.

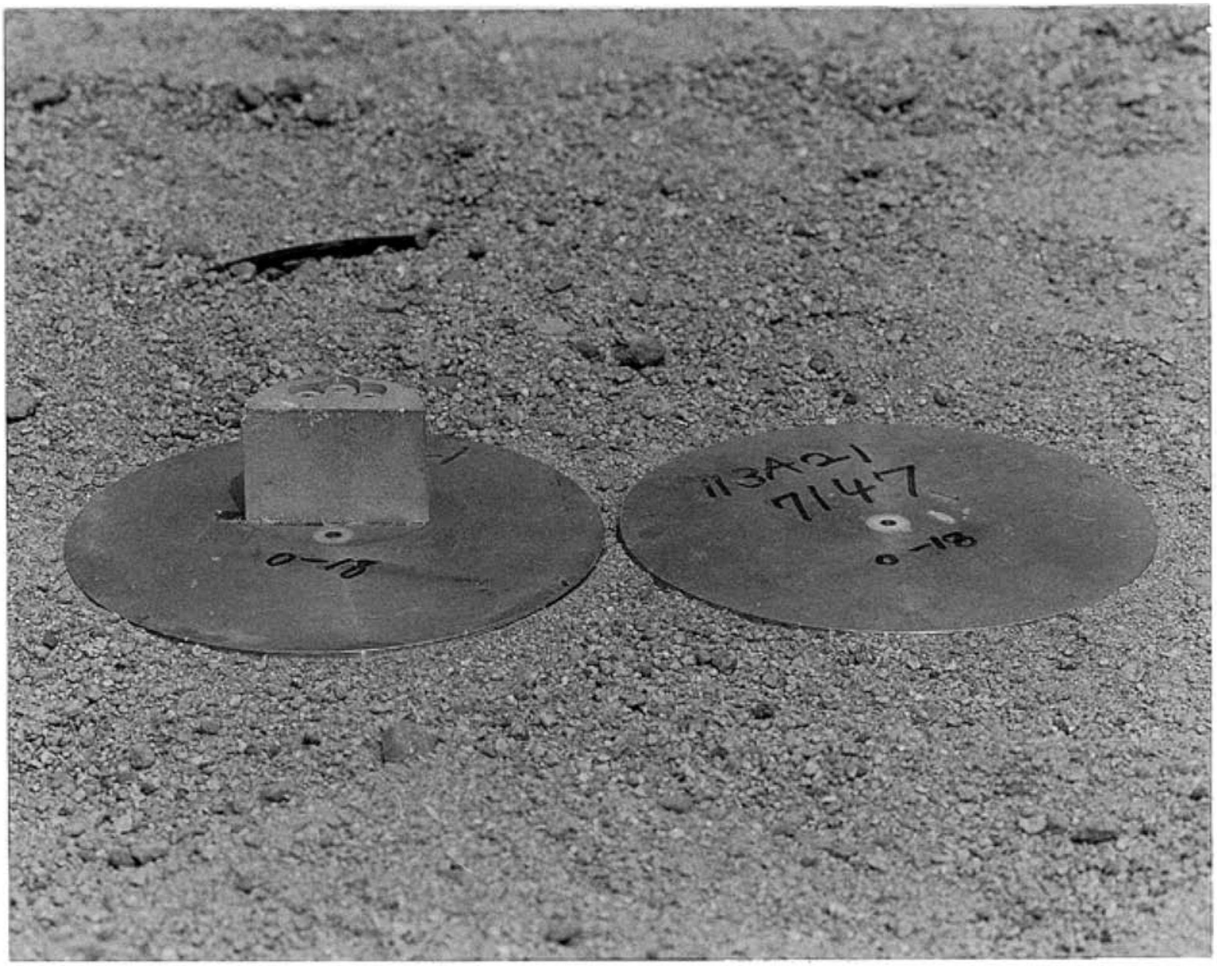

Fig. 7. Gauge mounts.

Fig. 8. Instrumentation system.

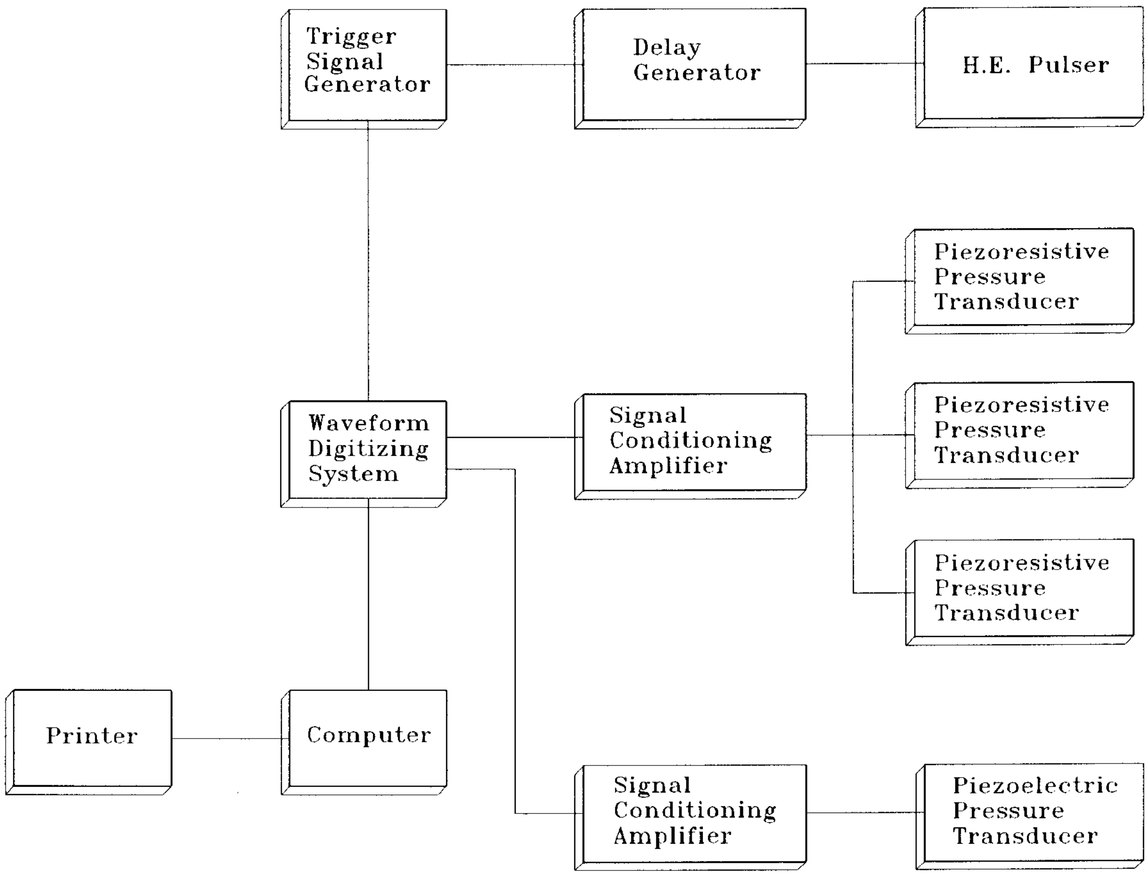

Fig. 8. Instrumentation system.

Fig. 9. Typical pressure-time and impulse-time histories.

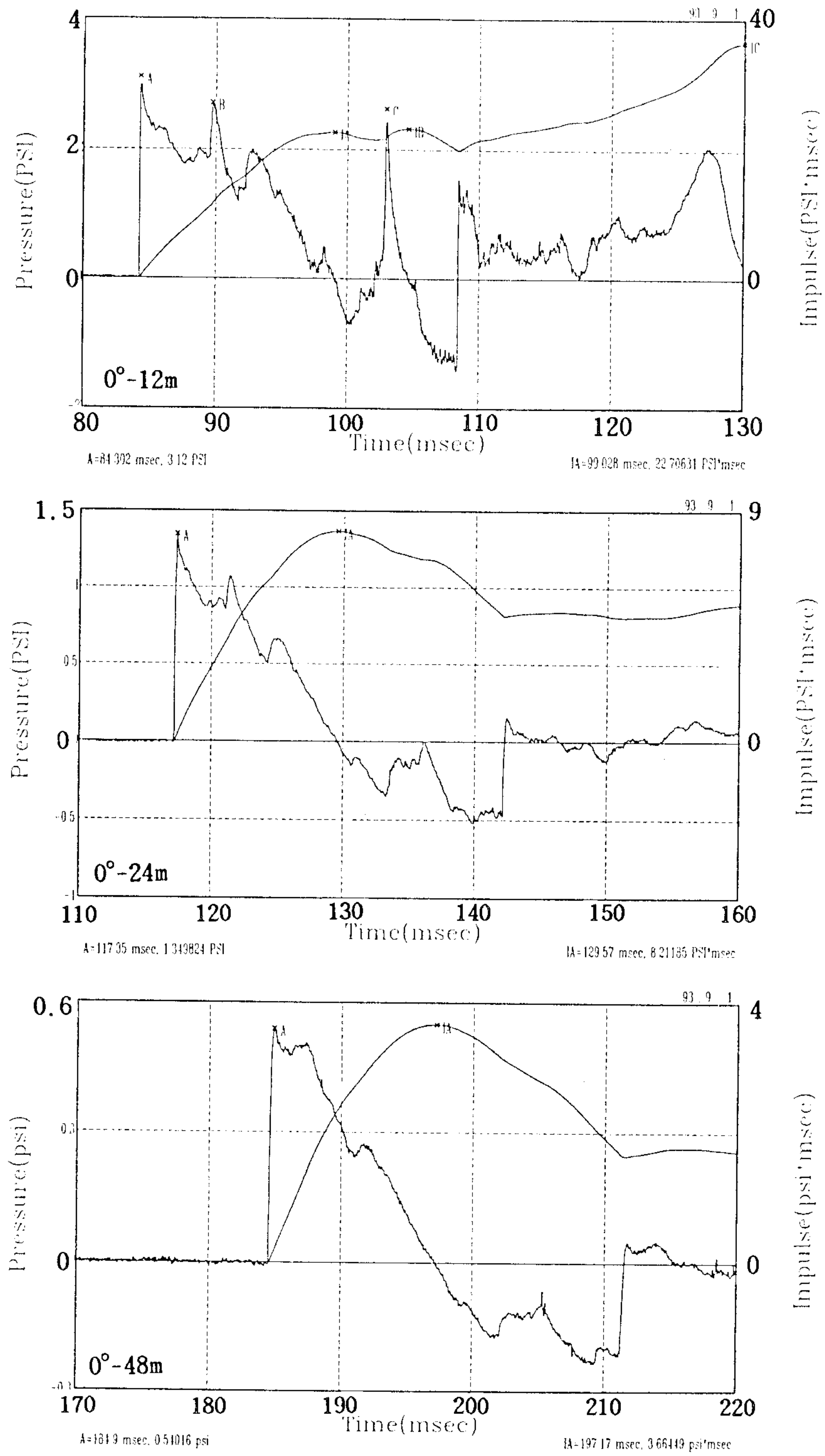

Fig. 9. Typical pressure-time and impulse-time histories.

Fig. 10. Scaled free-field blast pressure, Pw/P, vs. scaled distance, R/Dt, for small-scale magazines.

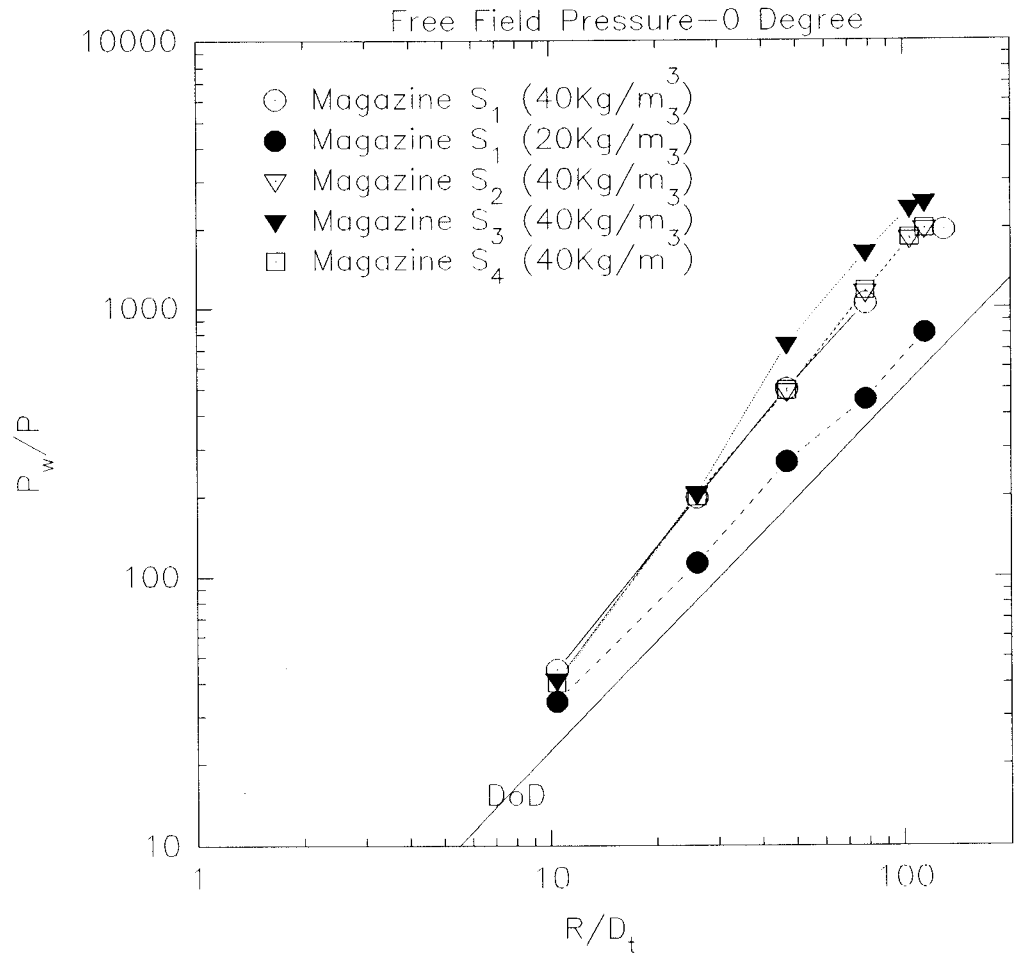

Fig. 10. Scaled free-field blast pressure, P_w/P, vs. scaled distance, R/D_t, for small-scale magazines.

Fig. 11. Initial acceleration as a function of relative hazard area(RHAR) for small-scale magazines.

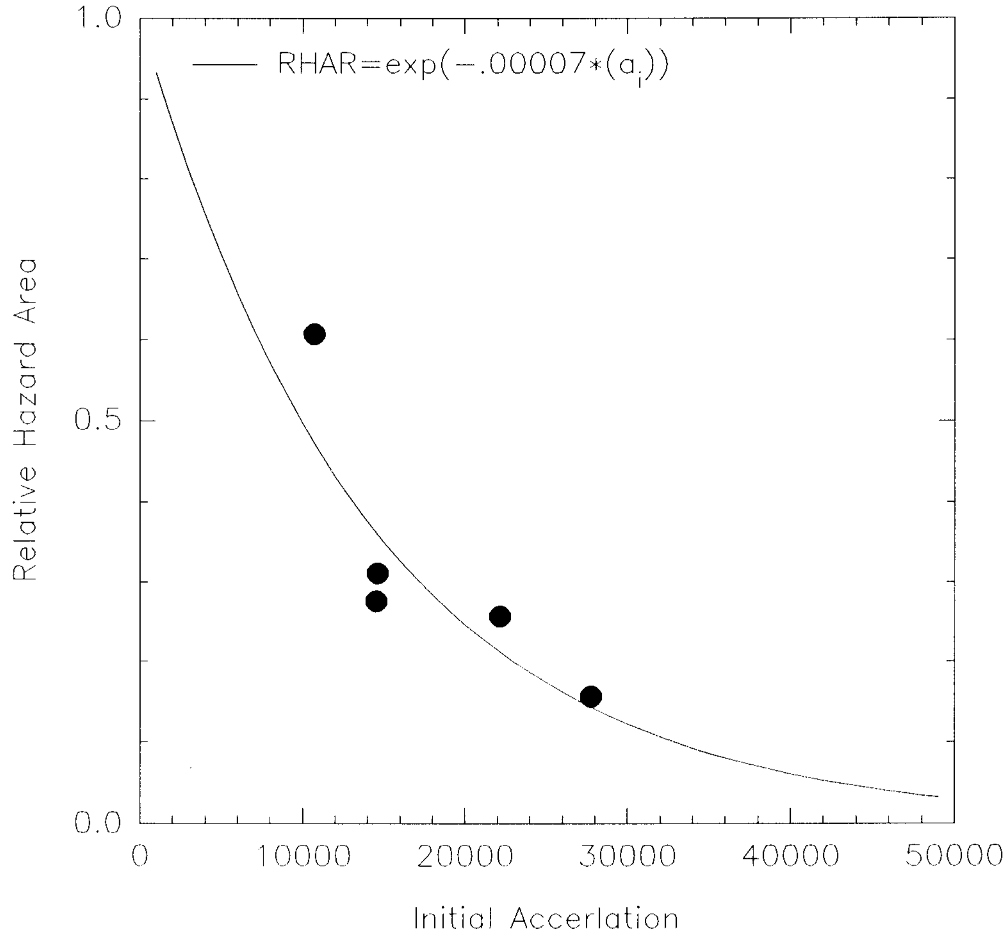

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Fig. 12. Scaled free-field blast pressure, Pw/P, vs. scaleddistance, R/Dt, for intermediate-scale magazines.

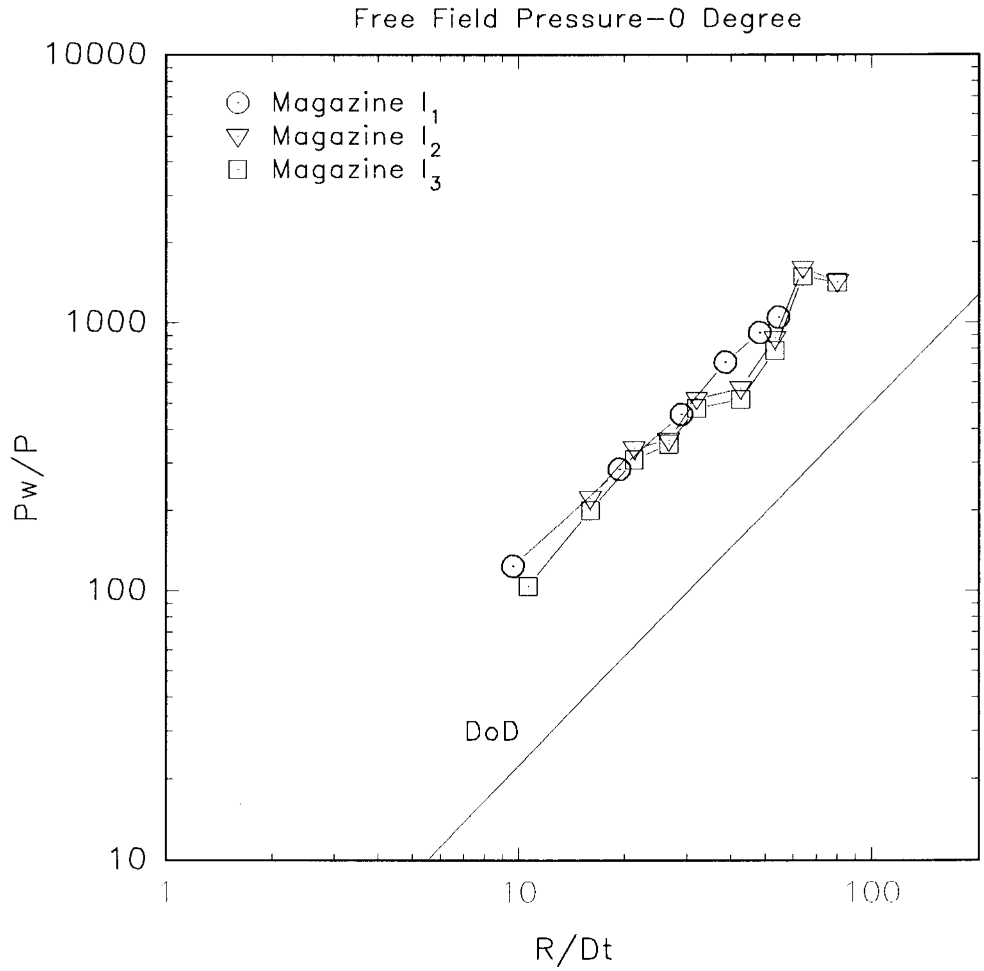

Fig. 12. Scaled free-field blast pressure, P_w/P, vs. scaled distance, R/D_t, for intermediate-scale magazines.